OAK RIDGE National Laboratory

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# Neutron Multiplicity


**PRESENTED BY**

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U.S. DEPARTMENT of ENERGY

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# PROMPT MULTIPLICITY AND CAPTURE-TO-FISSION RATIO

## Prompt neutron multiplicity

- Event $i$: $\nu_p^{(i)}$ = # prompt neutrons
- Prompt nubar:

$$\bar{\nu}_p(E) = \sum_{n \geq 0} n\, P(n \mid E)$$

- $\bar{\nu}_p$ is 2–3 for $E \approx E_{th}$
- Total: $\nu = \nu_p + \nu_d$, $\bar{\nu} = \bar{\nu}_p + \bar{\nu}_d$
- Source term $S(E, E') = \bar{\nu}(E)\, \chi(E, E')$ with $\chi$ (PFNS) normalized to unity

## Capture-to-fission and $\eta$

- $\alpha(E) = \dfrac{\sigma_\gamma(E)}{\sigma_f(E)}$
- If $\sigma_a = \sigma_f + \sigma_\gamma$:

$$\sigma_a = \sigma_f\,(1 + \alpha)$$

- Reproduction factor:

$$\eta(E) = \frac{\bar{\nu}\,\sigma_f}{\sigma_a} = \frac{\bar{\nu}}{1 + \alpha}$$

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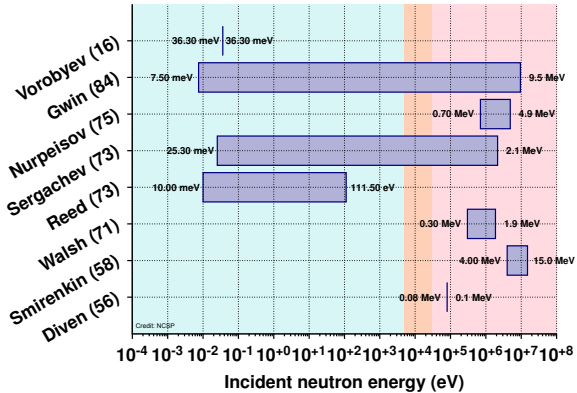
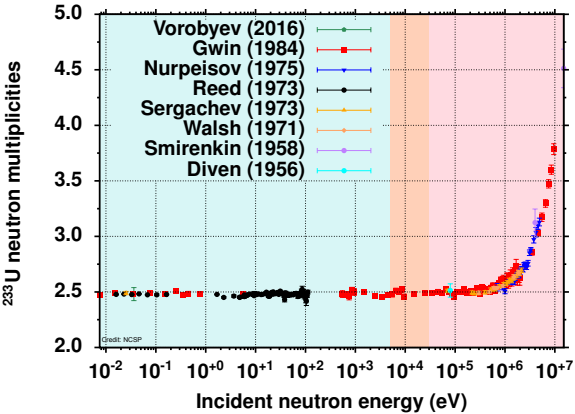
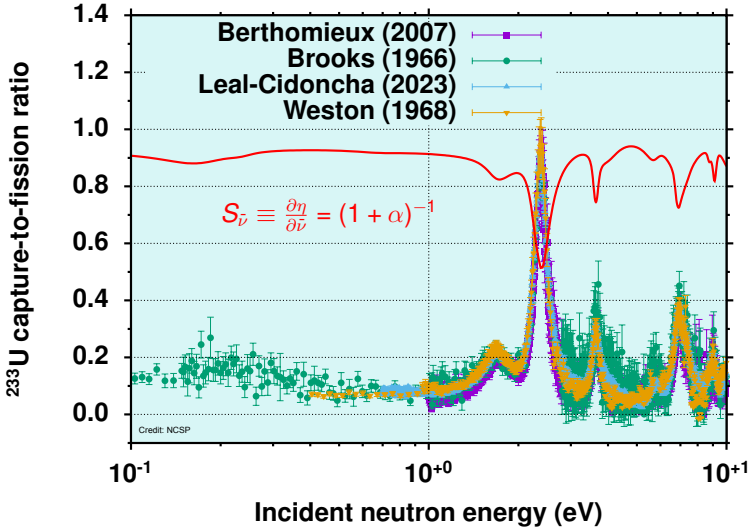
Nubar is key observable requested with the most stringent accuracy, typically 0.25–0.5%

# $^{233}U(\bar{\nu}_p)$ MEASURED DATA

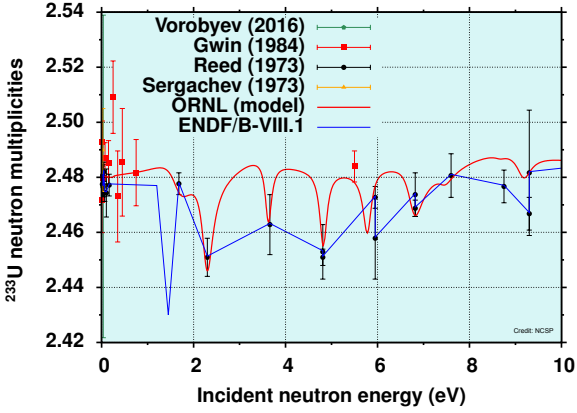


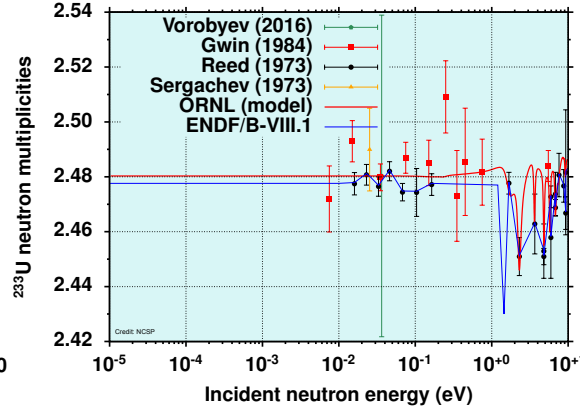



# $^{233}$U($\bar{\nu}_p$) SENSITIVITY PROFILE and $\alpha(E)$



# EVALUATED AND MEASURED DATA



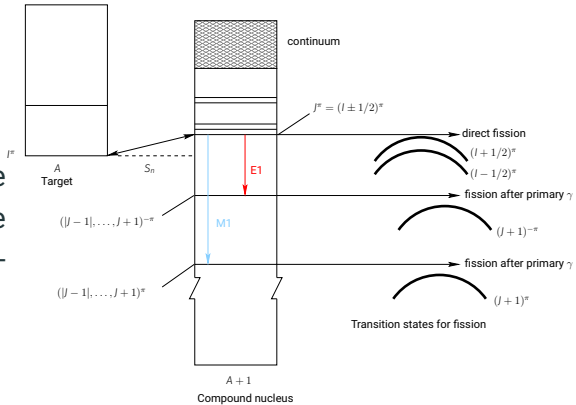
# PROMPT MULTIPLICITY MODEL

- A linear function of E is expected:

$$\bar{\nu}_p(E) = \bar{\nu}_0 + \frac{\partial \bar{\nu}}{\partial E} E$$

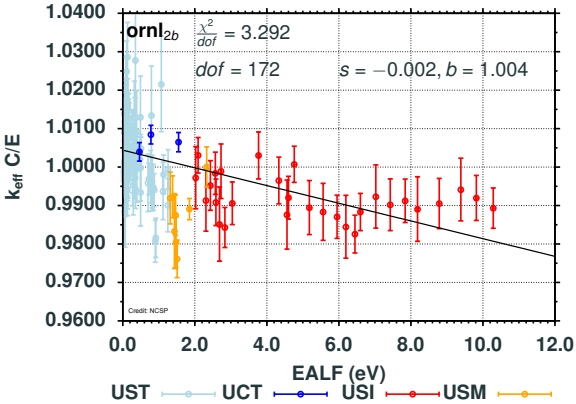
- Departures from linear behavior have been shown and competition of the (n,$\gamma$f) process and the (n,f) direct fission process[a]:

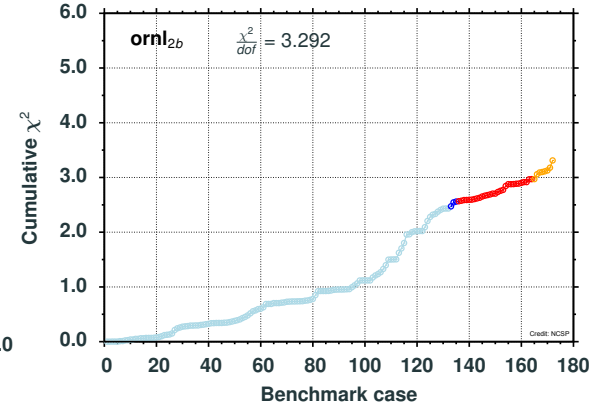
$$\bar{\nu}(E) = \bar{\nu}_p(E) - \Delta\bar{\nu}(E; \Gamma_f)$$




[a] Phys. Rev. **C**10, 1402 (1974)

# IMPACT ON CRITICALITY BENCHMARKS



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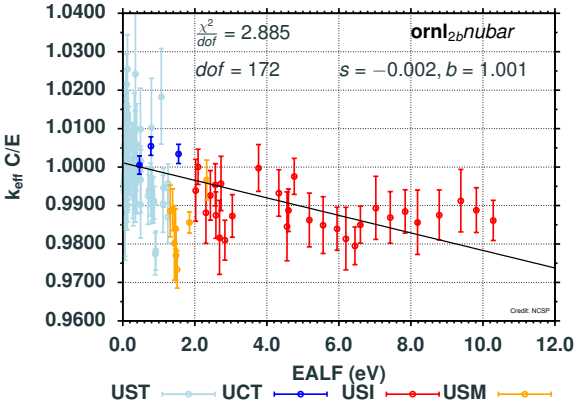


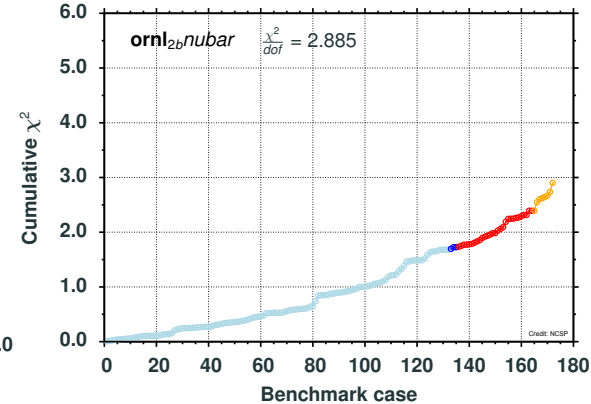

# ESSENTIAL POINTS

- The average number of neutrons from fission is a key observable used to calculate the reactivity of nuclear materials
- Scarce availability of high-fidelity and high-resolution measured data
- Considerable impact on criticality benchmark behavior
- Sensitivity profile inversely proportional to capture-to-fission ratio
- Models to incorporate energy dependent fluctuations in $\bar{\nu}_p$ are being developed

# ANNOUNCEMENT

## 2026 R-matrix workshop on methods and applications

- Where : ORNL
- When : 13–17 July 2026
- Topic : Neutron induced nuclear data library

**Organizing Committee**

- Marco Pigni (ORNL)
- Carl Brune (OU)
- James deBoer (UND)
- Gerry Hale and Mark Paris (LANL)
- Konstantinos Kravvaris (LLNL)
- Edward Simpson (ANU)
- Jakub Skowronski (INFN)
- Ian Thompson (LLNL)

# ACRONYMS

| | |
|---|---|
| ANU | Australian National University |
| EALF | Energy of Average neutron Lethargy causing Fission |
| ENDF | Evaluated Nuclear Data File |
| INFN | Istituto Nazionale di Fisica Nucleare |
| LANL | Los Alamos National Laboratory |
| LLNL | Lawrence Livermore National Laboratory |
| NCSP | Nuclear Criticality Safety Program |
| ORNL | Oak Ridge National Laboratory |
| OU | Ohio University |
| PFNS | Prompt Fission Nuclear Spectrum |
| UND | University of Notre Dame |

# ACRONYMS

- UST ≡ U(ranium) S(olution) T(hermal), EALF<1.6 eV (140 cases)
- UCT ≡ U(ranium) C(omposition) T(hermal), 0.6<EALF<1.8 eV (3 cases)
- USM ≡ U(ranium) S(olution) M(ixed), 1.2<EALF<2.5 eV (8 cases)
- USI ≡ U(ranium) S(olution) I(ntermediate), 2<EALF<10.4 eV (29 cases)
- UMF ≡ U(ranium) M(etal) F(ast), EALF>700 keV (10 cases)